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REPORT

MRL-R-800

THE EFFECTS OF C/M RATIO ON THE CONTROLLED FRAGMENTATION OF CYLINDERS USING EXTERNAL NOTCHING

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David S. Saunders

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DECEMBER, 1980

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ABSTRACT

The effects of C/M (HE charge to cylinder mass) ratio on the degree of control of fragmentation exerted by external longitudinal notching are investigated. Two series of experiments are conducted. In one series the cylinder wall thickness is varied to induce weight scaling and in the other both the cylinder dimensions and notch pitching are varied to induce number scaling.

Although both weight and number scaling with C/M ratio are feasible for notched cylinders, the results demonstrate that there are limitations to the degree of control exerted by the notching. Both weight and number scaling appear to be limited by the propensity for the operation of natural fragmentation mechanisms between the notches and weight scaling is also limited by geometric factors.

The filling of the notches with an epoxy resin produces an increase in the degree of control of fragmentation for both weight and number scaling cylinders.

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Although both weight and number scaling with C/M ratio are feasible for notched cylinders, the results demonstrate that there are limitations to the degree of control exerted by the notching. Both weight and number scaling appear to be limited by the propensity for the operation of natural fragmentation mechanisms between the notches and weight scaling is also limited by geometric factors.

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C O N T E N T S

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THE EFFECTS OF C/M RATIO ON THE CONTROLLED FRAGMENTATION OF CYLINDERS USING EXTERNAL NOTCHING

1. INTRODUCTION

Earlier work, reported by Lamborn (1973), used external longitudinal and circumferential notches in the walls of cylinders to effect the break-up of the cylinders on the detonation of the explosive filling. His report discussed in detail the effects of notch geometry, the hardness of the steel cylinders and the pitch of the notches; however, only relatively low C/M (HE charge to cylinder mass) ratios were used. Subsequent work by Lamborn (1976) showed that, in a limited number of tests, increasing the C/M ratio resulted in a decreased yield of primary fragments (i.e., those intact fragments resulting directly from the longitudinal notching). While the filling of the notches with an epoxy resin (to suppress the formation of a Munro jet on the notches) significantly improved the yield of primary fragments at lower C/M ratios, there was little improvement at the high C/M ratios used. This suggested that the wider fragments associated with the larger cylinders (constant notch pitching was used for all cylinders) broke up as a result of natural fragmentation mechanisms between notches. From these results it appeared that the degree of control of fragmentation by external notching might be reduced at high C/M ratios. The work demonstrates a need for an understanding of the effects of C/M on the weight and number scaling behaviours of notched cylinders (see next paragraph) if the prediction of notching configurations for controlling the break-up of cylinders is to be done with confidence.

Scaling rules for naturally fragmenting cylinders are predictive rules to allow the extrapolation of the fragmentation behaviours of cylinders beyond the cylinder dimensions used in tests. They are mathematical expressions relating fragmentation parameters to those geometric parameters which describe the cylinders. The prediction of the fragmentation of naturally fragmenting cylinders has been studied by Walsh (1973) and Walsh and Bedford (1975). Their scaling rules were largely based on C/M ratio.

Number scaling shows that the number of fragments of similar weight linearly increases with the C/M ratio of the cylinders used for the test and this is assumed to hold for larger cylinders. Weight scaling on the other hand shows that the weight of fragments increases linearly with the C/M ratio

The present work investigates whether scaling rules based on C/M ratio are feasible for cylinders where fragmentation is controlled by notching. Either weight or number scaling can be artificially imposed on the cylinder by the cylinder geometry and the presence of notches; consequently, the objective of the present work was to assess the effectiveness of these notches in maintaining fixed scaling behaviours.

2. AIM

The aim of the present work was to investigate, in more detail, the effects of C/M ratio on the degree of control of fragmentation attainable by external longitudinal notching, both unfilled and filled with an epoxy resin, in order to be able to predict the effects of changes in the dimensions of the fragmenting body. The proposal was to determine whether number and weight scaling can be used to describe the distribution of fragment numbers and sizes over a range of C/M ratios.

3. EXPERIMENTAL

Two sets of experiments were made; one in which C/M was varied by changes in wall thickness for constant outside diameter (WSC series) and the other where C/M was varied by outside diameter for constant wall thickness (NSC series). The results of the two experiments can be assessed as:

(1) weight scaling, (WSC series)

and (2) number scaling, (NSC series)

All the cylinders were of similar length and were longitudinally notched only. The notch width was 0.8mm ± .03, the notches being cut to various depths into the wall of the cylinders as outlined in Tables I and II. Details of the specimens are given in Sections 3.2 and 3.3.

3.1 Material

The fragmentation cylinders were machined from bar stock of steel to AISI 1050, the analysis being given in Table III, and the cylinders were notched prior to heat treatment.

All cylinders were austenitized at 850°C for 30 min., quenched into oil and then tempered at 425°C for 1 h to give an average hardness of 410 HV30.

3.2 Weight Scaling Cylinders (WSC Series)

The dimensions of the cylinders are given in Table I.

The cylinder dimensions chosen for this part of the work were based on those used in the work reported by Lamborn (1973). While it was not possible to match cylinder sizes exactly, an external radius of 16.9mm was used which gave a series of specimens which could be compared with those used in earlier work.

In the weight scaling series of cylinders two notch configurations were used. One configuration had a constant ratio of notch depth, d, to wall thickness, wt, (d/wt = 0.52) and the other maintained a constant material thickness below the base of the notch (wt-d = 2.3mm). The wall thicknesses of each family of cylinders were varied to give C/M ratios ranging from 0.1 to 0.7. An 18° pitch for the notches was maintained so that 20 long fragments per cylinder might be produced. Two specimens of each cylinder size were tested, one of each size of which had the notches filled with an epoxy resin, (viz. WSC/A2, B2, C2, D2, E2 and F2).

3.3 Number Scaling Cylinders (NSC Series)

The dimensions of the cylinders are given in Table II.

In this series of experiments, the C/M ratios were chosen to match those of the WSC series. This was achieved by varying the diameter of cylinders with the wall thickness kept constant. The pitch of the longitudinal notches was varied with C/M ratio so that an ideal fragment mass/unit length* was constant for all cylinders, i.e., the fragment width was the same. It should be noted that cylinders NSC/E1 and E2 are of the same dimensions as WSC/E1 and E2. The notch configuration maintains a constant wall thickness below the base of the notch (wt-d = 2.3mm).

Two specimens of each cylinder size were tested; one of each size of which had the notches filled with an epoxy resin, (viz. NSC/A2, B2, C2, D2, E2 and F2).

3.4 Fragmentation Tests

The high explosive filling used in the cylinders was open cast RDX/TNT/BW : 55/45/1. The casting techniques confined the formation of solidification piping in a header which was subsequently discarded. No lead-out of explosives was used in any of the cylinders because in the case of the large cylinders any excess would have exceeded the capacity of the

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* The ideal fragment mass/unit length is the theoretical mass/unit length of the fragment if there is no secondary fragment produced below the root of the notch.

fragmentation pit used. For consistency, then, all charges were machined flush with the ends of the cylinders.

The cylinders were detonated in an air cavity under water (after Burman and Walsh (1978)) and the resulting fragments were collected by magnets after pumping out the water.

4. RESULTS

The fragments recovered from each cylinder were sorted into four categories, the main three of which are illustrated in Fig 1. The categories are:

(1) Primary fragments

(2) Split Primary fragments

(3) Secondary fragments

(4) Fines and End fragments.

The primary fragments were of main interest, and the size and mass/unit length of these fragments at a given C/M ratio varied quite significantly with the filling of the notches and possibly the depth of material below the notch.

The side faces of the primary fragments from cylinders with unfilled notches have been shown by Lamborn (1973) to consist of two regions, an outer region being the remaining section of the machined surface of the original notch and an inner region resulting from the action of a jet formed within the notch (Fig 2). Some corner fracture, from the jet to the outer surface of the cylinder, can result in the reduction in the mass/unit length of the primary fragments from cylinders with unfilled notches (see Section 5).

The side faces of the primary fragments from those cylinders with epoxy resin filled notches consisted entirely of the original surface of the notch (Fig 3). The mass/unit length of fragments from cylinders with filled notches was greater than that of fragments from cylinders of similar geometries but with unfilled notches. This effect is a result of the location of shear fracture lower in the notch in the case of the filled notch, together with the virtual elimination of corner fracture, (see Section 5).

The primary fragments (and indeed the fragments in the other categories) recovered ranged in length. This is due to the fact that no attempt was made to control the transverse break-up of the cylinders by notching. It was observed that transverse break-up was more pronounced in those cylinders of high C/M ratios and in those with unfilled notches.

The split primary fragments are those primary fragments which have also fractured longitudinally as a result of natural fragmentation mechanisms operating in the wall of the cylinders between adjacent notches. One of the side faces of these fragments exhibited characteristics of natural fragmentation, i.e., a radial tensile fracture leading to the outer surface of the cylinder with a shear fracture to the inner wall (Walsh (1973) and Walsh and Bedford (1975); see Figs 1(c) and 4).

The secondary fragments were generally triangular in cross section, and were formed by shear fractures emanating from the lower regions of the jet to the inner wall of the cylinders (Fig 5). The size of these fragments varied considerably in the case of the weight scaling series and was largely a function of wall thickness (constant d/wt ratio) whether or not the notches were filled with the epoxy resin, (see also Lamborn (1976)).

Table IV lists the total recovery of primary, split primary, and secondary fragments as a percentage by weight of the total recovery. Total recovery is used here rather than the original cylinder weights to allow to some extent for anomalous recoveries. For reference, the weights of the unfilled cylinders are given in Table V. Clearly extra fragments not recovered from earlier firings have been included in some of the recovery data.

5. DISCUSSION

The total weight of fragments in the primary category will be used as a basis for determining the degree of control exerted by the notching. This is an arbitrary criterion for assessment purposes, but it follows that used in other studies of the formation by notching of intact fragments of a particular shape and size. The degree of control of fragmentation, ϕ, exerted by notching is defined as:

$$\phi = \frac{\Sigma \text{ primary fragment masses}}{\Sigma \text{ all fragment masses}}$$

$$\phi \times 100 = \%\text{ primary fragments from Table IV}$$

This simple parameter gives some quantitative measure of the controlled break-up of the longitudinally notched cylinders in terms of the weight yield of fragments of a pre-determined width or mass/unit length.

The formation of primary fragments of a pre-determined size and shape by longitudinal and circumferential notching has been discussed in detail by Lamborn (1973). The present work is concerned only with the control of fragmentation with longitudinal notches and hence in this work no circumferential notches are used. The overall length of the primary fragments is determined by the propensity for the operation of natural fragmentation mechanisms along the length of the cylinder on detonation of the explosive filling.

Table VI lists the measured average mass/unit length (units of gm/mm) of fragments recovered from both the WSC and NSC cylinders. This method of describing the size of the fragments readily differentiates between fragments from cylinders with unfilled and filled notches. This in turn correlates well with the amount of corner fracture and also the size of secondary fractures formed below the notch (i.e., the cross sectional shape of the primary fragments). However, to maintain a reasonable basis for the comparison of fragments from various C/M ratios, the fragments were sorted so that except for WSC A1, no corner fracture was present on those used for the measurement of mass/unit length. In the case of the series with unfilled notches, the proportion of corner fracture increases with C/M ratios above 0.47. At C/M = 0.71, about 50% of the corners are lost due to corner fracture.

5.1 Weight Scaling Cylinders (WSC)

Figures 6(a) and 6(b) show sections through primary and secondary fragments from cylinders with two different C/M ratios in the WSC series. It is immediately obvious that the filling of the notches with the epoxy resin produces primary fragments of higher mass/unit length (Fig 7) and consequently a higher mass yield of primary fragments, as shown in Tables IV(a) and VI. Those primary fragments from cylinders with filled notches exhibit less corner fracture from the notch face to the outer wall of the cylinder, consistent with the observations of Lamborn (1976). This is considered by Lamborn to be the result of the filling in the notch suppressing the operation of the jet and hence promoting fracture in the vicinity of the notch root before the shear strain reached that necessary for adiabatic shear which normally results in corner fracture, (Fig 6(a)).

Generally, the degree of control of fragmentation in those cylinders with d/wt = 0.52 appears to be only slightly influenced by C/M ratio, Table IV(a). However, for those weight scaling cylinders with (wt-d) = 2.3mm, see Table I, the effect of C/M ratio appears to be more significant, viz. those cylinders with a constant attenuation distance (material thickness) below the notch, see also Fig 8. Thus, secondary fragments form a larger percentage of the total recovery at high C/M ratios due to the smaller wall thickness and constant material thickness below the notch. In this series of cylinders, it appears that the effects of C/M ratio arise from the geometry of the specimen and are not exclusively due to changes in expansion velocities.

As the depth of notching becomes shallower, at a given C/M ratio, the primary fragments tend to become triangular in cross section and of smaller mass/unit length due to the location of the jet further out in the wall of the cylinder. The secondary fragments show a corresponding increase in cross section. This is specifically illustrated by the WSC/D1, D2, D3, D4 series of cylinders (Fig 8 and Table IV(a)).

At the highest C/M ratio (with d/wt = 0.52), the yield of primary fragments is lower than for intermediate ratios and can be associated with a slightly higher yield of split primary fragments, particularly for the cylinder with unfilled notches. The splitting is largely due to the operation of natural fragmentation mechanisms in the material between the

notches due to the higher expansion velocities in those cylinders of high C/M ratios.

The increase in the yield of secondary fragments at intermediate and low C/M ratios appears to be associated with the larger wall thickness and the constant d/wt ratio rather than the lower expansion velocities (Table IV(a)). Here, as with the above series, (wt-d) = 2.3mm, it appears to be difficult to distinguish between the two effects. Some support for the observation that geometry plays an important role may be gained from the WSC series with filled notches. In this series (WSC/C2, D2 and E2), the secondary fragments constitute a substantial proportion of the recovery due to suppression of the operation of the jet, which therefore results in fracture from the root of the notch only being instrumental in the break-up of the cylinder. Thus the effects of wall thickness and notch depth appear more significant than C/M ratio.

It is likely that cylinder WSC/E1 has yielded anomalous results with a much lower yield of primary fragments than expected and a correspondingly high yield of split primary fragments. The general trends of the results do not suggest that such a high proportion of split fragments should form. Cylinder NSC/E1 is similar in geometry and the recovery result of this cylinder is included in Fig 8.

By combining the trends of the two notch configurations shown in Fig 8, it appears reasonable to postulate that a family of curves can be drawn for a range of d/wt ratios showing ϕ increasing with increasing d/wt ratio. The curves may not have the same form as that for d/wt = 0.52, and indeed the results suggest that ϕ may increase more rapidly with decreasing C/M for d/wt ratios greater than 0.52.

5.2 *Number Scaling Cylinders (NSC)*

It is expected in this section of the work that, if number scaling exists, the total weight of primary fragments would be linearly related to the C/M of the cylinders and that the primary fragments from the cylinders would all be of a similar mass/unit length. Figure 9 confirms that the fragment mass/unit length is largely unaffected by C/M ratio, but the effects of filling the notch are seen as an increase in mass/unit length of the fragments and an increase in the yield of primary fragments (Table IV(b)). The reasons for this are discussed in Section 5.1. Figures 10(a) and (b) shows sections through primary and secondary fragments from two different C/M ratios. The similarity of the fragments from the two ratios confirms that number scaling is possible.

The results from Table IV(b) are plotted in Fig 11 as the variation of the total weight of primary fragments for each cylinder with C/M ratio. This also shows some degree of number scaling is possible, with filled and unfilled notches, but the filling of the notches substantially improves the yield.

The effect of C/M on the degree of control of fragmentation by notching, ϕ, appears to be insignificant for the ranges of C/M and notc

pitch investigated in this work. The value of ϕ remains virtually unchanged for cylinders with both filled and unfilled notches in walls of constant thickness, with average values of 0.72 and 0.53, respectively.

The recovery result from cylinder NSC/A1 appears to be anomalous because of the pick-up of fragments from previous firings.

The facts that ϕ is virtually unaffected by C/M, and that the number of split primary fragments is also approximately constant with C/M for the filled and unfilled series, suggests that the propensity for longitudinal splitting is a result of the stress state generated within the cylinder walls rather than expansion velocity, i.e., an effect of notch geometry. This, however, is an observation made using only one specific notch depth. Clearly, the stress state is modified by the filling of the notch and hence, in these experiments, results in an increase in yield of primary fragments at all C/M ratios.

5.3 General Comments on the Applicability of Scaling Rules

Both series of experiments outlined in this work were based on variable C/M ratios but used different geometries to vary C/M ratio. It is usual to associate an increasing C/M ratio with a higher expansion velocity or initial fragment velocity, Gurney (1943). Because the size of explosive charge had to be limited, it was not possible to maintain a constant ratio of cylinder length to internal diameter in these experiments. Consequently, it is possible that increases in internal diameter do not significantly alter the expansion velocities. This effect is reported by O'Shea and Watmough (1969) and it is possible that it is due to the loss of detonation products through the relatively large top and bottom of large internal diameter cylinders.

However, transverse break-up of the primary fragments together with increasing longitudinal fracture and corner fracture increases as C/M increases with cylinders with unfilled notches. It seems reasonable to associate the increase in the amount of transverse fracture with increasing longitudinal strain generated with increasing C/M ratio. This suggests some influence of expansion velocity but its magnitude is undetermined. This work also supports the suggestion by Lamborn (1976) that those cylinders with filled notches break-up earlier in their expansion than equivalent cylinders with unfilled notches. Early break-up does not allow the build-up of such high stresses and hence results in a reduction of the above-mentioned effects.

The work has demonstrated that both weight and number scaling can be imposed on fragmenting cylinders by external notching and that this is more effective if the notches are filled.

The degree of control in the weight scaling experiments is complicated by the effects of reducing wall thickness and changes in the depth of material below the root of the notch. Thus, it is difficult to describe weight scaling only in terms of C/M ratio since it is usual for the notch configuration also to change with C/M ratio. Hence the development

of scaling rules for predictive work would need to consider variations if geometry. These changes in geometry, whether or not the notches are filled, significantly influence the shock interactions within the walls of the cylinders, which influence the break-up of the cylinders as well as the effects of the C/M ratio.

The degree of control in the number scaling experiments appears largely unaffected by the C/M ratio, thus, within the limitations of the experiments, the production of fragments of a pre-determined mass/unit length appears feasible. For number scaling, it should be possible to develop scaling rules based on the C/M ratio.

The width of the primary fragment, was limited in both series of experiments by the operation of natural fragmentation mechanisms between the notches. The observation that the propensity for longitudinal splitting increases with C/M ratio suggests that fragments much wider than those formed in this work cannot be formed at high C/M ratios. The filling of the notches with a suitable medium, however, should increase the fragment widths above those formed from unfilled notches.

6. CONCLUSIONS

Under the experimental conditions used:

(a) External notching of cylinders can be used to pre-determine their break-up, even at high C/M ratios.

(b) The degree of control of external notching is greater for the C/M ratios investigated if the notches are filled with a suitable medium, such as an epoxy resin.

(c) Both weight and number scaling appear feasible for cylinders with fragment shapes and sizes pre-determined by external notching with constant d/wt ratios.

(d) The effectiveness of notching on weight scaling is largely limited by geometric factors, but the propensity for the operation of natural fragmentation mechanisms also limits the fragment mass/unit length. However, the effectiveness of notching on number scaling is largely limited by the operation of natural fragmentation mechanisms between notches at high C/M ratios.

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TABLE I

DIMENSIONS OF WEIGHT SCALING CYLINDERS (WSC)

C/M Ratio	0.71	0.55	0.47	0.35	0.35	0.23	0.10
Specimen No.(1) WSC/	A1, A2	B1, B2	C1, C2	D1, D2	D3, D4	E1, E2	F1, F2
External Radius, Ro, mm	16.9	16.9	16.9	16.9	16.9	16.9	16.9
Internal Radius, Ri, mm	14.8	14.3	13.9	13.2	13.2	12.1	9.6
Length, h, mm	83.0	83.0	83.0	83.0	83.0	83.0	83.0
Wall thickness, wt, mm	2.1	2.6	3.0	3.7	3.7	4.8	7.3
Pitch of Notches	18°	18°	18°	18°	18°	18°	18°
Notch Depth, d, mm	1.1	1.4	1.6	1.9	1.4	2.5	5.0
Notch Width, s, mm	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Notch Configuration(2) wt–d, mm	1.0	1.2	1.4	1.8	2.3	2.3	2.3
d/wt	0.52	0.54	0.53	0.51	0.38	0.52	0.68
No. of Ideal Fragments(3) (see text)	20	20	20	20	20	20	20

(1) Two series, WSC/A1, B1, C1, D1, D3, E1, F1 have unfilled notches and WSC/A2, B2, C2, D2, D4, E2, F2 have notches filled with an epoxy resin.

(2) One group of notched cylinders, WSCA1/A2, B1/B2, C1/C2, D1/D2 and E1/E2 has d/wt = .0.52 and the other, WSCD3/D4, E1/E2 and F1/F2, (wt–d) = 2.3 mm, i.e. a constant material thickness below the root of the notch.

(3) No secondary fragments produced.

TABLE II

DIMENSIONS OF NUMBER SCALING CYLINDER (NSC)

C/M Ratio	0.71	0.55	0.47	0.35	0.23	0.10
Specimen No. (1) NSC/	A1, A2	B1, B2	C1, C2	D1, D2	E1, E2	F1, F2
External Radius, Ro, mm	38.5	31.3	27.7	22.6	16.9	11.1
Internal Radius, Ri, mm	33.7	26.5	22.9	17.8	12.1	6.3
Length, h, mm	83.0	83.0	83.0	83.0	83.0	83.0
Wall Thickness, wt, mm	4.8	4.8	4.8	4.8	4.8	4.8
Pitch of notches	7.2°	9°	10.3°	12°	18°	20°
Notch Depth, d, mm	2.5	2.5	2.5	2.5	2.5	2.5
Notch Width, s, mm	0.8	0.8	0.8	0.8	0.8	0.8
Notch Configuration (2) wt-d, mm	2.3	2.3	2.3	2.3	2.3	2.3
d/wt	0.52	0.52	0.52	0.52	0.52	0.52
No. of Ideal Fragments (2) (see text)	50	40	35	30	20	12

(1) Two series, NSC/A1, B1, C1, D1, E1, F1 have unfilled notches and NSC/A2, B2, C2, D2, E2, F2 have notches filled with an epoxy resin.

(2) No secondary fragments produced.

TABLE III

COMPOSITION OF STEEL (GRADE 1050) FOR EXTERNALLY NOTCHED CYLINDERS, WT%

C	Si	Mn	S	P
0.52	0.03	0.76	0.028	0.025

TABLE IV(a)

RECOVERY DATA FOR EXTERNALLY NOTCHED CYLINDERS, WEIGHT SCALING CYLINDERS,

(WSC SERIES)

Specimen	WSC A1	WSC B1	WSC C1	WSC D1	WSC D3	WSC E1	WSC F1
Recovery, g	113.2	140.3	160.3	187.5	202.2	238.1	321.5
% Primary	53.8	59.9	59.1	43.8	45.3	33.0	82.5
% S. Primary	19.8	16.1	18.2	31.5	11.8	37.0	2.5
% Secondary	5.0	8.0	9.3	13.1	21.6	19.7	12.1
	WSC A2	B2	C2	D2	D4	E2	F2
Recovery, g	118.9	151.0	154.3	190.0	189.6	241.0	334.4
% Primary	71.0	80.0	83.3	79.1	63.4	78.0	83.0
% S. Primary	13.4	6.1	11.0	1.4	4.15	0	0
% Secondary	7.5	6.6	6.6	16.6	23.2	19.7	15.88

TABLE IV(b)

RECOVERY DATA FOR EXTERNALLY NOTCHED CYLINDERS, NUMBER SCALING CYLINDERS,

(NSC SERIES)

Specimen	NSC A1	NSC B1	NSC C1	NSC D1	NSC E1	NSC F1
Recovery, g	640.0	297.6	340.0	288.5	248.5	156.4
% Primary	52.9	50.0	51.0	53.6	53.2	56.0
% S. Primary	9.8	13.2	13.1	16.1	18.7	14.1
% Secondary	22.7	23.5	23.9	22.4	21.9	27.7
	NSC A2	B2	C2	D2	E2	F2
Recovery, g	601.5	465.2	408.6	347.8	276.7	167.7
% Primary	72.6	72.5	73.5	70.2	69.5	70.8
% S. Primary	0.7	0.4	0.15	0.48	0.2	0.5
% Secondary	14.6	18.1	18.4	9.2	22.8	23.6

TABLE V

WEIGHTS OF EXTERNALLY NOTCHED CYLINDERS, g

C/M Ratio	0.71	0.55	0.47	0.35	0.35	0.23	0.10
WSC	A1 124	B1 150	C1 168	D1 204	D3 212	E1 255	F1 338
WSC, filled notch	A2 125	B2 152	C2 172	D2 209	D4 213	E2 258	F2 345
NSC	A1 634	BB1 511	C1 449	D1 354		E1 258	F1 147
NSC, filled notch	A2 648	B2 519	C2 455	D2 355		E2 262	F2 156

TABLE VI

PRIMARY FRAGMENTS

AVERAGE MASS/UNIT LENGTH FOR EXTERNALLY NOTCHED CYLINDERS

(g/mm)

C/M Ratio	0.71	0.55	0.47	0.35	0.35	0.23	0.10
WSC Series, Unfilled notch	A1	B1	C1	D1	D3	E1	F1
measured	0.051 (1)	0.075	0.078	0.093	0.084	0.100	0.160
ideal fragmentation (2)	0.075	0.091	0.104	0.125	0.136	0.156	0.207
WSC Series, Filled notch	A2	B2	C2	D2	D4	E2	F2
measured	0.067	0.083	0.088	0.098	0.077	0.113	0.167
ideal fragmentation	0.075	0.091	0.104	0.125	0.136	0.156	0.207
NSC Series, Unfilled notch	A1	B1	C1	D1		E1	F2
measured	0.097	0.097	0.102	0.093		0.111	0.110
ideal fragmentation	0.155	0.155	0.155	0.144 (3)		0.155	0.155
NSC Series, Filled notch	A2	B2	C2	D2		E2	F2
measured	0.117	0.113	0.116	0.106		0.114	0.114
ideal fragmentation	0.155	0.155	0.155	0.144 (3)		0.155	0.155

(1) low mass/unit length due to corner fracture.

(2) ideal fragmentation, no secondary fragments produced.

(3) incorrect cylinder design produced fragments smaller than those of the remainder of the series.

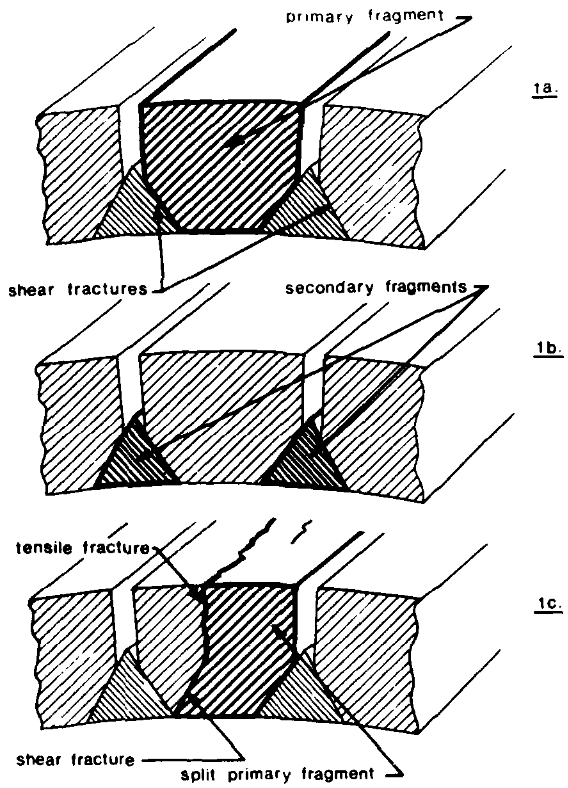
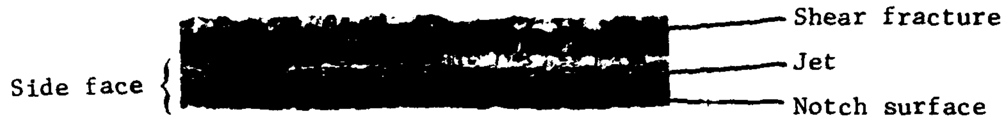


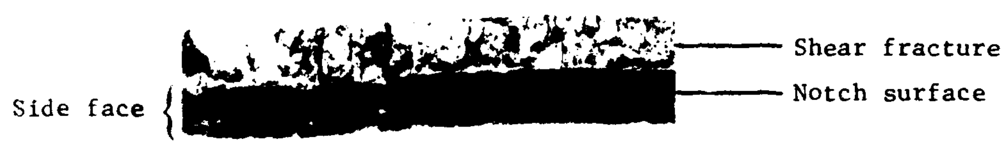
FIG. 1 - Illustration showing the formation of fragments of the three major categories observed.

(a) the primary fragment
(b) the secondary fragment
(c) the split primary fragment



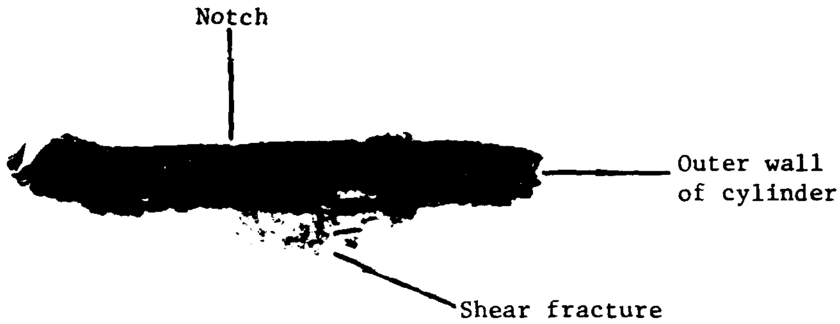
NSC/E1

FIG. 2 - Side face of a fragment from cylinder NSC/E1. ×3.5



NSC/E2, filled

FIG. 3 - Side face of a fragment from cylinder NSC/E2, with notches initially filled with an epoxy resin. ×3.5

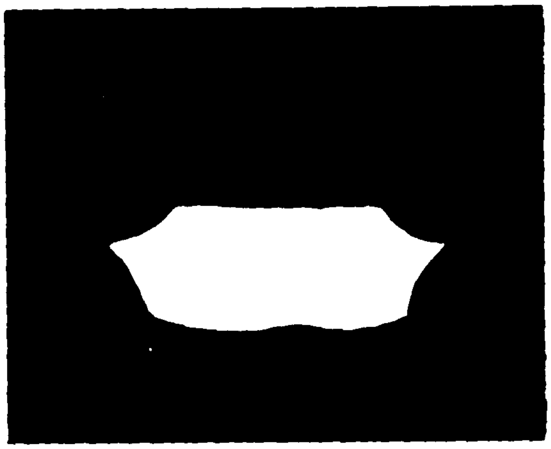


NSC/A1

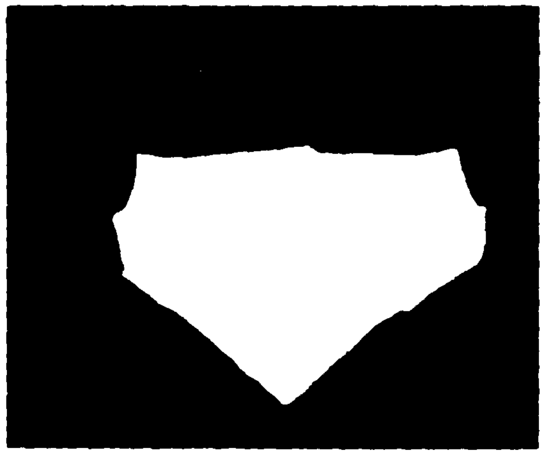
FIG. 4 - Split primary fragment from cylinder NSC/A1. ×3.5

WSC/A1 WSC/E1

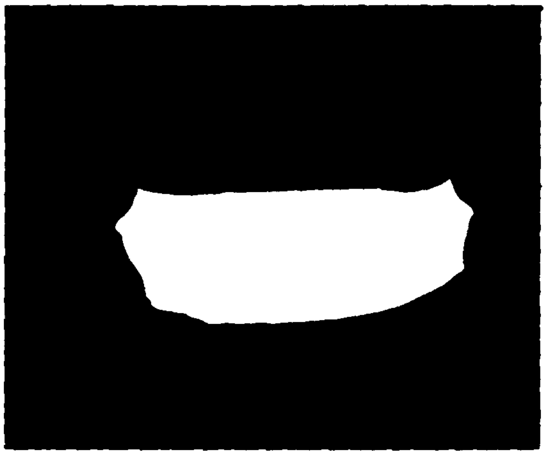
FIG. 5 - Secondary fragments from two cylinders from the WSC series, showing the effects of wall thickness on the size of the secondary fragments formed. ×3.5



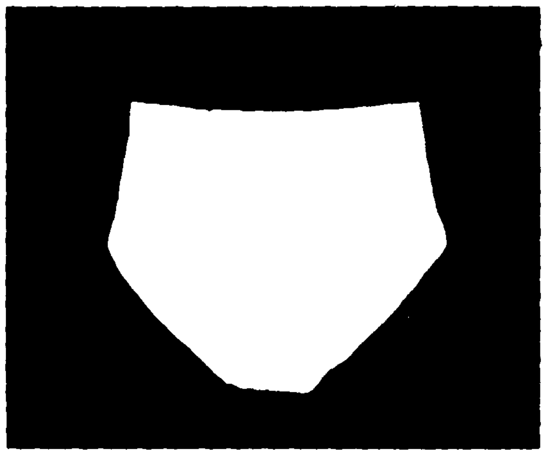
WSC/A1
C/M = 0.71



WSC/E1
C/M = 0.23

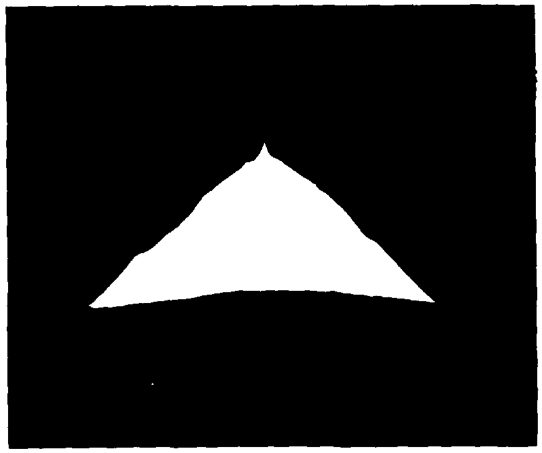


WSC/A2, filled notch
C/M = 0.71



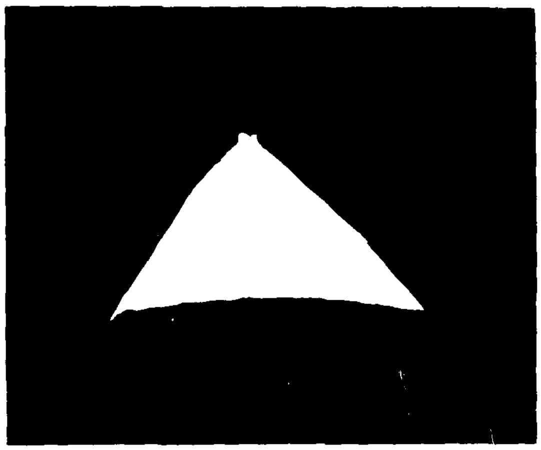
WSC/E2, filled notch
C/M = 0.23

FIG. 6(a) - Transverse sections of primary fragments from weight scaling cylinders. ×10



WSC/E1

C/M = 0.23



WSC/E2, filled notch

C/M = 0.23

FIG. 6(b) - Transverse sections of secondary fragments from weight scaling cylinders which produced large secondary fragments. ×10

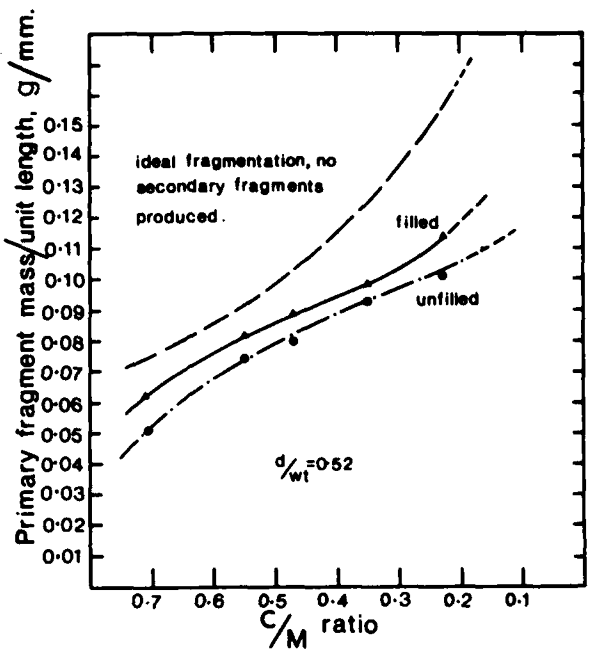


FIG. 7 - Variation of average primary fragment mass/unit length with C/M ratio for fragments recovered from weight scaling cylinders, for the case of d/wt = 0.52 with both filled and unfilled notches.

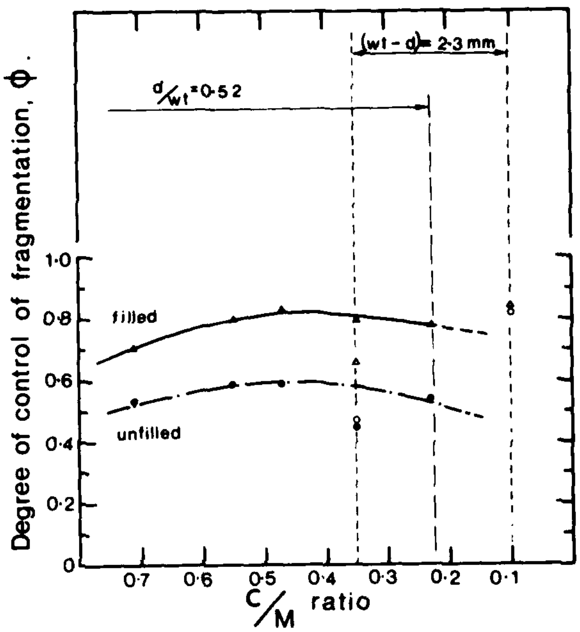


FIG. 8 - Variation of the degree of control of fragmentation, ϕ, with C/M ratio for weight scaling cylinders for the case d/wt = .52 (*closed symbols* ▲,●). The open symbols on the graph (△,○) are for the case of (wt-d) = 2.3 mm with C/M = 0.23 common to both. No graph is drawn for cylinders conforming to (wt-d) = 2.3 mm.

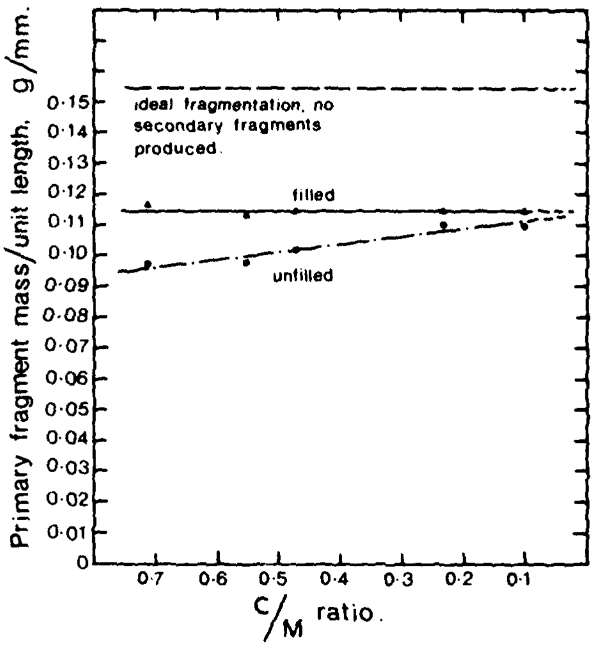
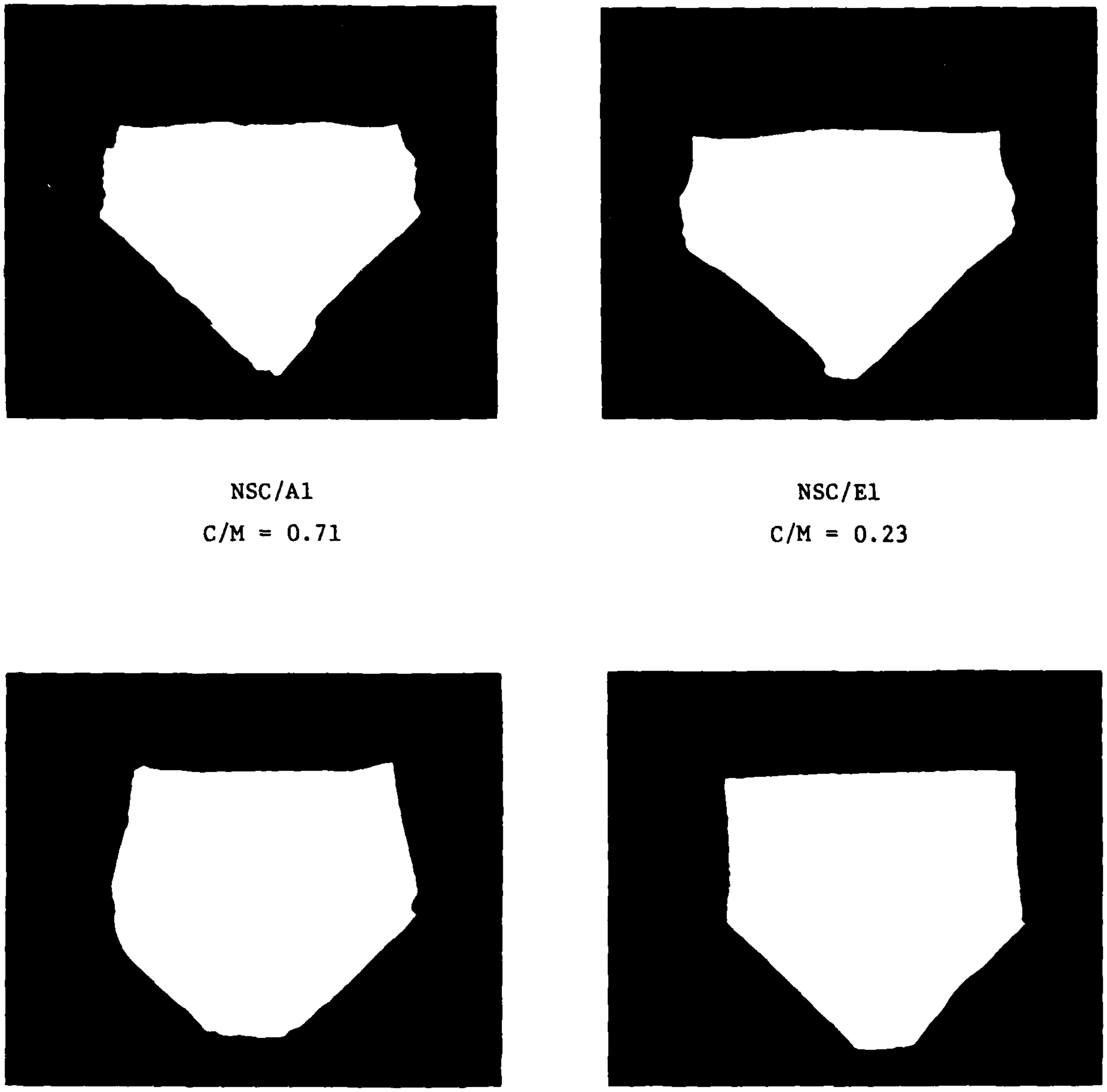


FIG. 9 - Variation of primary fragment mass/unit length with C/M ratio for number scaling cylinders with both filled and unfilled notches.



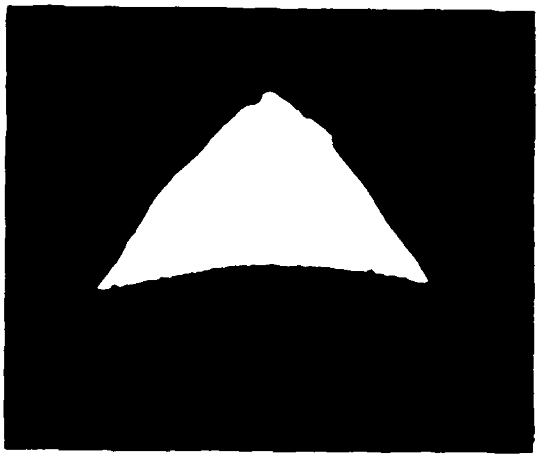
NSC/A1
C/M = 0.71

NSC/E1
C/M = 0.23

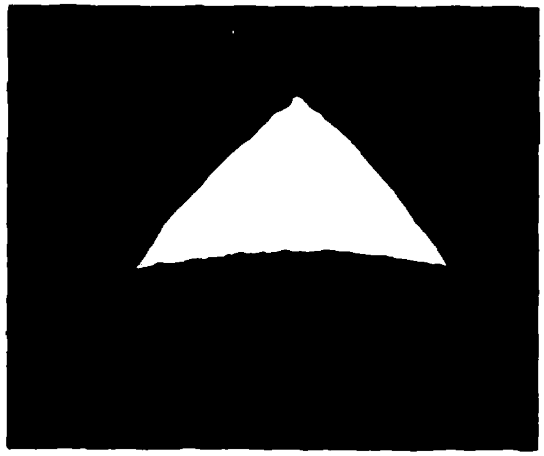
NSC/A2, filled notch
C/M = 0.71

NSC/E2, filled notch
C/M = 0.23

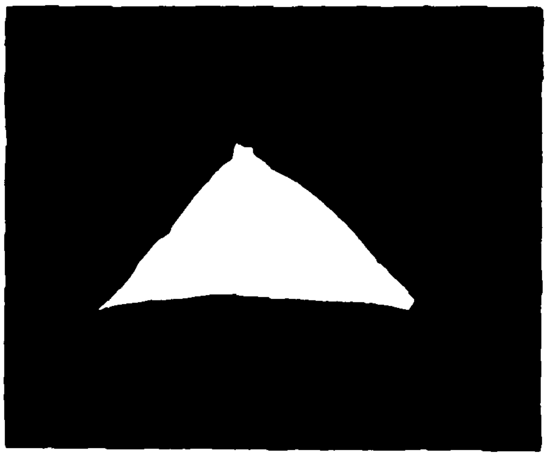
FIG. 10(a) - Transverse sections of primary fragments from number scaling cylinders. ×10



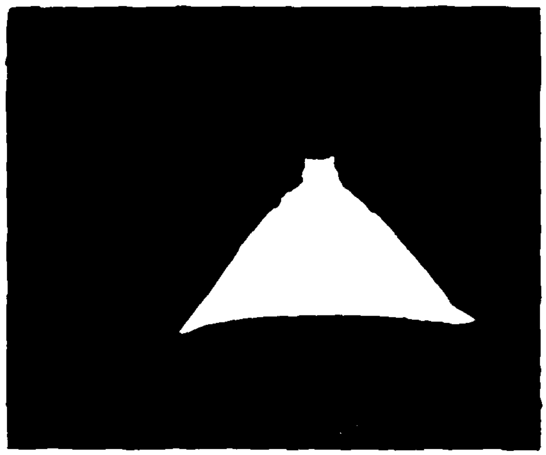
NSC/A1
C/M = 0.71



NSC/E1
C/M = 0.23



NSC/A2, filled notch
C/M = 0.71



NSC/E2, filled notch
C/M = 0.23

FIG. 10(b) - Transverse sections of secondary fragments from number scaling cylinders. ×10

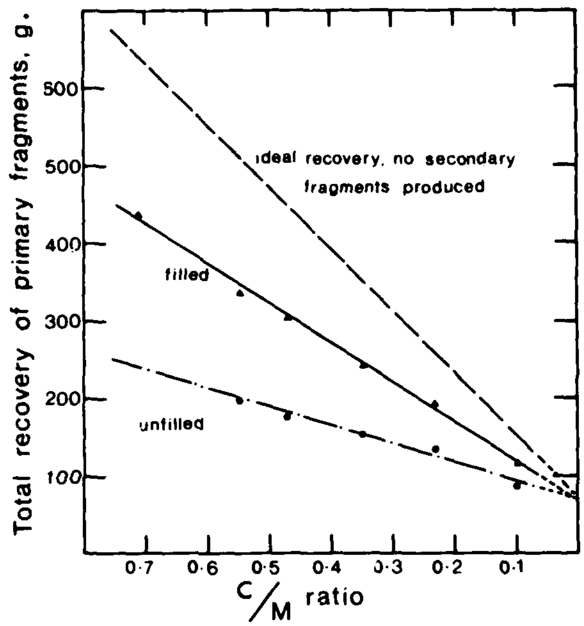


FIG. 11 - Variation of total recovery of primary fragments with C/M ratio for number scaling cylinders with both filled and unfilled notches.

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